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COMPLETE SPECIFICATION

Panel Structure providing a High Acoustic Transmission Loss

We, BOLT BERANEK AND NEWMAN INC. a corporation duly organised and existing under the laws of the State of Massachusetts, United States of America, of 50 Moulton Street, Cambridge, Massachusetts, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to walls, partitions, panels and other structures, hereinafter generically referred to as "panel structures", and more particularly to panel structures for providing a high acoustic transmission loss over a wide band of acoustic frequencies. The terms "acoustic" and "sound" will be used in reference to vibrations at audible frequencies and the term "vibrations" will embrace mechanical vibrations at all frequencies, including audible, sub-audible and super-audible frequencies.

As is explained in our copending application No. 581/60, filed 7th January, 1960 (Serial No. 943256), for "Panel and the Like of High Acoustic Transmission Loss", panel structures heretofore employed for structurally separating spaces, such as rooms, radiate acoustic energy applied to them, either by transmission or reflection, particularly at the high sound frequencies, as a result of the setting-up of transverse waves in the panel of velocity comparable to that of acoustic energy in the air surrounding the panel. The said copending application describes a new and improved three ply construction of panel structures that completely overcomes this disadvantage by imbuing such panel structures with means for preventing the effective shear-wave velocity within the interior medium of the panel structure from becoming comparable with the velocity of acoustic energy in the air; limiting the same so that the shearing wave velocity in the inner medium of the

structure is not greater than 0.7 of the velocity of sound in air.

A shear-wave is defined as a wave which, when applied to a complex panel structure composed of two surface members or facings with an interior medium therebetween, causes bending and alternate extension and compression of the surface members which results in slip between the surface members and the interior medium, the interior medium being subjected to shear stress.

Such panel structures have been found to be highly satisfactory. In some cases, however, it is desirable to keep the cost of manufacture of panel structures embodying the constructional and performance characteristics above discussed as low as possible. In addition, it is desirable in some applications to keep the constructional details of the interior medium of the panel structures as simple as possible.

An object of the present invention, therefore, it to provide a new and improved panel structure of the character described that is relatively inexpensive to manufacture and of relatively simple construction, and yet is designed to provide the high acoustic transmission loss attainable in panel structures made in accordance with the teachings of the said co-pending application. A further panel structure is disclosed in our further co-pending patent application No. 37575/63 (Serial No. 954908) which is a Division of this application.

In one aspect the invention consists of a panel structure for providing high transmission loss at frequencies within a desired band of acoustic frequencies comprising a pair of outer surface members one or both having inwardly extending transversely rigid supports attached to or integral with the inner surfaces thereof, said supports being spaced from one another, and an interior medium separating said supports and attached to the inner surfaces

thereof by coatings of an adhesive to provide a coupling between said surface members, said interior medium including a material which is substantially incompressible and has a low resistance to shear in relation to its density to enable it to flex easily in response to shear stress caused by bending movement of said surface members, to permit propagation along said interior medium of said band of acoustic frequencies with a transverse-wave velocity of less than substantially seven-tenths of the velocity of said frequencies in air.

In another aspect the invention consists of a panel structure for providing high transmission loss at frequencies within a desired band of acoustic frequencies comprising a pair of plate-like outer surface members, and an interior medium separating said surface members and fixed thereto by coatings of an adhesive to provide a coupling between said surface members, said interior medium being composed of layers of a material which is substantially incompressible and has a low resistance to shear in relation to its density to enable it to flex in response to bending movements of said surface members, said layers being fixed to said surface members, and a plurality of transverse rigid supports spaced from each other and extending between said layers and being joined thereto by coatings of adhesive to provide a coupling between said layers, to permit propagation along said interior medium of said band of acoustic frequencies with a transverse-wave velocity of less than substantially seven-tenths of the velocity of said frequencies in air.

Selected embodiments of the invention will now be described in connection with the accompanying drawings, Figure 1 of which is a fragmentary longitudinal section of a panel structure constructed in accordance with the present invention;

Figures 2 and 3 are similar views of modified structures;

Figure 4 is a view similar to Figure 3 of still a further modification;

Figure 5 is a fragmentary longitudinal section similar to Figure 4 of a preferred embodiment of the invention;

Figure 6 is a similar view of another modified structure;

Figure 7 is a graph presenting experimentally obtained performance characteristics of a panel constructed in accordance with the embodiments of Figures 4 and 5; and

Figures 8 and 9 are fragmentary views of further modifications illustrated in the act of bending.

The criteria set forth in the above-numbered co-pending application, for producing the phenomena required in order to achieve high transmission loss, are several-fold. The velocity of the effective shear wave propagation in the interior medium of the panel between the outer surface members or facings

must not exceed 0.7 of the velocity C_0 of sound in the surrounding air; preferably not greater than two-third of the velocity C_0 of sound in air surrounding the panel. To achieve this requires a low ratio of shear modulus-to-density of the interior medium or core of the panel structure. Furthermore, the Young's modulus of the interior medium must be less than the Young's modulus of either of the surface members. Finally, if it is to be assured that the acoustic transmission loss be not reduced by mechanical resonances, set up transversely between the two panel surface members, through the interior medium, the thickness of the panel and the characteristics of the interior medium must be such as to ensure that the transverse mechanical resonant frequency lies outside the band of acoustic frequencies whose transmission through the panel structure is to be prevented.

Referring to Fig. 1, a panel structure that conforms to the above-mentioned criteria is constructed of relatively inexpensive materials and is of simple structural design. The panel structure has surface members or facings 3 and 3' bounding an interior medium of thickness b . That interior medium is shown comprising inwardly extending transversely rigid supports 5 and 5', integral with the inner surfaces of the facings 3 and 3' though, as later explained, an integral construction is not essential even if, in some cases, it is preferred. The rigid inwardly extending supports 5, 5' are shown longitudinally spaced from one another along the length of the panel structure, the spaces being illustrated as cavities or openings 2. The length of the rigid supports is illustrated by the dimension r and the length of the spaces 2 is illustrated by the dimension h .

Sandwiched between the rigid supports 5, 5' and in contact therewith is a relatively thin elastic layer 4 as of rubber, synthetic elastomers, appropriately plasticised plastic materials such as polyvinyl chloride, and similar soft but substantially incompressible materials. The layer 4 is adhered to the rigid supports 5, 5' by the application of a coating of a bonding adhesive, not shown, to one or both of the surfaces to be joined. The reason for the requirement of substantial incompressibility resides in the fact that it is desired to maintain a high resistance to transverse extension or compression in the layer 4, without impairing its ability to flex in response to bending movement of the surface members 3, 3' (which imposes a shear stress on the layer 4), thereby to avoid a detrimental mechanical resonance that could otherwise be produced at acoustic frequencies in panel structures of useful thickness.

In order to attain the 0.7 velocity criterion above discussed, the following approximate relationship has been found to determine the necessary value of the shear modulus μ and

total layer thickness b_2 of the layer 4, the mass m per unit area (density) of the panel, and the percent of the surface area A_T of the surface members 3, 3' that is internally supported by the plurality of spaced relatively rigid regions 5, 5', the regions adjacent the spaces 2 being internally unsupported:

$$\sqrt{\frac{\mu b^2 A_s}{m b_2 A_T}} \leq 0.7 C_0; \quad (1)$$

where C_0 is the velocity of propagation of acoustic energy in the air surrounding the panel and the like, A_s is the effective cross-sectional area, measured parallel to the inner and outer surfaces 3, 3', occupied by the supports 5, 5' and thus representing the effective internal supported area of the surfaces 3, 3'.

In the case, for example, of substantially rectangular posts or other supports 5, 5', substantially planar surface members 3, 3', and a substantially planar layer 4, as shown in Fig. 1; this equation reduces to the approximate relationship:

$$\sqrt{\frac{\mu b^2 r^2}{m b_2 (r+h)^2}} \leq 0.7 C_0. \quad (2)$$

The medium 4 need not be constituted of a single layer but may be constructed of multiple layers. Materials appropriately laminated together may be used which will present the ability to flex in response to shear stress while providing high resistance to transverse extension or compression. In Fig. 2, for example, a pair of layers 4' is shown laminated with a thin layer or membrane 6, as of metal, glass or mica to assist in the provision of high resistance to transverse extension or compression without impairing the ability to flex under shear stress of the composite layer 4', 6.

Instead of placing the layer 4 or 4', 6 in the position shown in Figs. 1 and 2, it may be placed closer to one of the surface members 3 or 3' and, indeed, in the embodiment of Fig. 3, it is shown adjacent the surface member 3, with only the rigid supports 5' provided.

The invention is not limited to the use of a single layer 4 or of a single composite layer 4', 6. As shown in the preferred embodiment of Fig. 4 for example, a pair of layers 4'' is employed, one adjacent the inner boundary of each of the surface members 3, 3', with the plurality of spaced rigid supports 5 interposed between the inner surfaces of the layers 4''. In order to provide performance equivalent to that obtainable with the shearable layer of thickness b_2 of Figs. 1 and 3, the layers 4'' need each be only of thickness substantially $1/2 b_2$. The supports 5, moreover, could also be divided by one or more intermediate extending sheets similar to the sheet 6 of Fig. 2, preferably disposed substantially parallel to the faces 3, 3'. In effect,

this is illustrated in Fig. 8, where the central solid region 50 of the spacer means 5 acts as an intermediate stiff dividing member, as of gypsum or metal.

In Fig. 7, an experimentally obtained graph is presented showing the relationship between the transverse or bending wave velocity propagated along a panel constructed in accordance with the embodiment of Fig. 4 (plotted along the ordinate in units of feet per second) and the frequency of the acoustic energy (plotted in units of cycles per second along the abscissa). The dimensions of the experimental structure were as follows: inner and outer surfaces members 3 and 3' were 18-gauge steel plates; the layers 4'' were of gum rubbers, 35 Durometer, secured to the surface members 3, 3' and the supports 5 with an epoxy adhesive and of thickness $1/2 b_2$ equal to 0.018 inches; rigid supports 5 of aluminium of thickness b_1 equal to 1 inch; and support length r equal to $1/2$ and space length h equal to 0.1 inch. It will be observed from Fig. 7 that a substantially constant transverse-wave velocity is achieved, well below the velocity of sound in air, over a broad band of acoustic frequencies, void of mechanical resonance effects. High transmission loss over this band can be obtained, that is comparable to the transmission loss obtainable with the structures described in the said copending application.

It is to be understood that the rigid supports 5, 5', need not assume the particular geometric configuration shown and described, but, as explained in the said earlier copending application, may take any of a variety of forms including, for example, appropriate honeycomb-like or spaced cell types of structures. Thus, in Fig. 6, a honeycomb-like supporting structure 5 is illustrated extending inwardly from the surface member 3', to sandwich a layer 4 against the inner boundary of the opposite surface member 3. In order to illustrate the versatility of the invention the supports 5 of Fig. 6 are shown kerfed to provide an even smaller contact area with the layer 4. The resulting further spaces 2' are illustrated as of length g , and the more limited regions of contact with the layer 4 are illustrated as of length j . Equation 2 then reduces, for this case, to the approximate relation:

$$\frac{b^2 r^2 j^2}{m b^2 (r+h)^2 (j+g)^2} \leq 0.7 C_0. \quad (3)$$

In all cases, the core sections b must be of materials relatively stiff in the transverse direction, such as the metal blocks before referred to, or a honeycomb construction, or materials such as gypsum, to mention but a few materials. The total transverse compliance should be sufficiently low that the mechanical resonant frequency lies well outside the useful band of acoustic frequencies, as before

explained. Preferably, an appreciable, if not the principal, part of the transverse compliance may reside in the layer 4.

The modification of Figure 9 shows block supports 50¹, with the regions A of the elastic material 4¹¹¹, in shear, and the regions B, between the blocks, bending as shown, to contribute to the assistance to shear.

In all of the above-described embodiments, any acoustic energy striking either of the panel surfaces can reflect back into the room or other space whence the acoustic energy originated. If it is desired to provide acoustic absorption at such surfaces, one or both of the outer panel surfaces may be perforated as shown in the case of the upper panel 3 of Fig. 5, having the perforations 7 therein. The perforated surface 3 may then be covered with an acoustically resistive layer or layers such as a fibrous blanket or covering 8 to achieve the above-described result of absorbing incident acoustic energy, in view of the action of the resistive layer or layers in combination with the air-permeable spaces 2 within the core. Resistive material could also be placed in such permeable spaces 2. If the resistive layer or layers 8 is or are applied to the outside surface of the perforated member 3, rather than on the inside thereof, where it or they would work equally well for acoustically absorptive purposes, the perforations will be concealed and an attractive wall-paper-like covering may be provided. It is to be understood that this modification may also be incorporated into all of the other embodiments of the invention for the purpose described.

Further modifications will occur to those skilled in the art, within the scope of the invention as defined in the appended claims.

WHAT WE CLAIM IS:—

1. A panel structure for providing high transmission loss at frequencies within a desired band of acoustic frequencies comprising a pair of outer surface members one or both having inwardly extending transversely rigid supports attached to or integral with the inner surfaces thereof, said supports being spaced from one another, and an interior medium separating said supports and attached to the inner surfaces thereof by coatings of an adhesive to provide a coupling between said surface members, said interior medium including a material which is substantially incompressible and has a low resistance to shear in relation to its density to enable it to flex easily in response to shear stress caused by bending movement of said surface members, to permit propagation along said interior medium of said band of acoustic frequencies with a transverse-wave velocity of less than substantially seven-tenths of the velocity of said frequencies in air.

2. A panel structure for providing high transmission loss at frequencies within a

desired band of acoustic frequencies comprising a pair of plate-like outer surface members, and an interior medium separating said surface members and fixed thereto by coatings of an adhesive to provide a coupling between said surface members, said interior medium being composed of layers of a material which is substantially incompressible and has a low resistance to shear in relation to its density to enable it to flex in response to bending movements of said surface members, said layers being fixed to said surface members, and a plurality of transverse rigid supports spaced from each other and extending between said layers and being joined thereto by coatings of adhesive to provide a coupling between said layers, to permit propagation along said interior medium of said band of acoustic frequencies with a transverse-wave velocity of less than substantially seven-tenths of the velocity of said frequencies in air.

3. A panel structure as claimed in claim 1 or 2 in which the thickness and incompressibility of said interior medium are such as to prevent mechanical resonance between said surface members at said frequencies.

4. A panel structure as claimed in claim 3 so arranged that said mechanical resonance occurs at a frequency outside the acoustic band of frequencies.

5. A panel structure as claimed in any preceding claim in which said surface members have a longitudinal stiffness greater than the longitudinal stiffness of said medium and in which the total surface area of said panel structure A_T ; the velocity of said band of frequencies in the air surrounding the panel structure, C_0 ; the thickness of said medium, b ; the mass per unit area of said panel structure, m ; the shear modulus of said medium, μ , and its thickness, b_2 ; and the effective cross-sectional area, A_s , of said supports parallel to the said surface area A_T of said panel structure are all related by the expression:

$$\sqrt{\frac{\mu b^2 A_s}{m b_2 A_T}} \leq 0.7 C_0.$$

6. A panel structure as claimed in claim 5, in which the said supports are of length r and the spaces therebetween are of length h , and the ratio $\frac{A_s}{A_T}$ is given substantially by the relationship

$$\frac{r^2}{(r+h)^2}.$$

7. A panel structure as claimed in claim 5 in which the said supports have their surfaces in contact with said medium subdivided by a plurality of further spaces or cavities which are out of contact with the said medium.

8. A panel structure as claimed in claim 7 in which the said supports have a length

- 5 r and a space therebetween of length h, and the length g of the said further spaces and length j of the portions of said supports in contact with the said medium between said further spaces have a relationship such that

the said ratio $\frac{A_s}{A_T}$ is given substantially by the expression:

$$\sqrt{\frac{\mu b^2 r^2 j^2}{m b_s (r+h)^3 (j+g)^3}} \leq 0.7 C_0.$$

- 10 9. A panel structure as claimed in any preceding claim in which the said medium comprises a relatively soft and incompressible material such as rubber.

- 15 10. A panel structure as claimed in claim 5 in which the said supports have a slotted surface in contact with said interior medium.

11. A panel structure as claimed in any preceding claim in which the interior medium comprises at least one substantially planar layer.

- 20 12. A panel structure as claimed in any

preceding claim in which the said interior medium comprises a multi-layer structure.

- 25 13. A panel structure as claimed in any preceding claim in which at least one of the said surface members is perforated and the perforations are exposed to acoustically absorbent means.

- 30 14. A panel structure as claimed in claim 13 in which the perforations are covered by an acoustically absorbent layer or layers on the outside of the panel structure.

- 35 15. A panel structure for providing high acoustic transmission loss in a band of acoustic-energy frequencies substantially in accordance with any one of the embodiments described herein and the Figure or Figures of the accompanying drawings relating to that embodiment.

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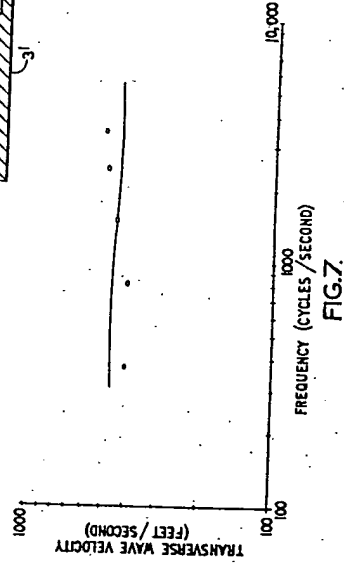
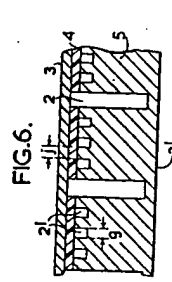
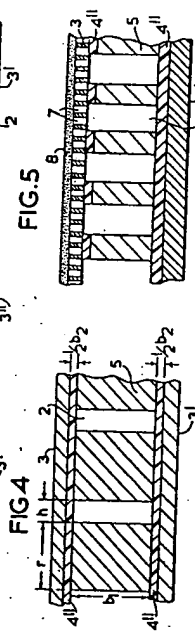
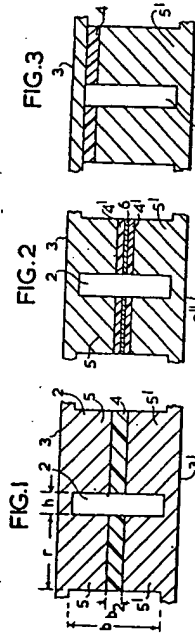


FIG. 7.

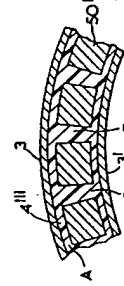


FIG. 9.

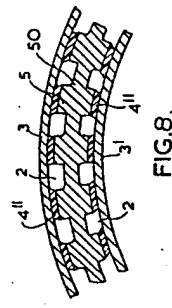


FIG. 10.

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